Cloud Properties of CERES-MODIS Edition 4 and CERES-VIIRS Edition 1

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Outline

- Motivation
- List of cloud properties in CERES Edition4 product:
  - SSF (Single Scanner Footprint)
- References for CERES Single & Multilayer Cloud Retrievals
- Examples of CERES MODIS & VIIRS results
- Validation results
- Summary
- Data ordering websites for SSF and CCCM

Motivation

• Clouds and the Earth's Radiant Energy System (CERES) is developing a long-term climate record of cloud properties and top-of-atmosphere & surface radiative fluxes

- shortwave (0 – 5 μm) and Total (0-100 μm) radiances measured (~20 km)
- cloud properties retrieved from imager on same platform (0.75 – 1 km)
- clouds & radiances merged to produce Single Scanner Footprint (SSF)

• Clouds used to select anisotropic directional models to convert radiance to flux

• Clouds used to compute surface and atmospheric radiant fluxes

• Cloud data used to determine relationships between radiation and clouds

• Cloud and radiation data used to validate climate models

=> need high quality cloud products

- reprocessing with new editions as state of the art advances

CERES MODIS

- MODIS on Terra (1030 LT Eq. crossing time), 1 km resolution, Jan 2000-
  on Aqua (1330 LT ECT), 1 km pixel resolution, June 2002-

- Edition 2 processing
  - *Aqua: through December 2014, will continue until ED4 ADMs completed*
  - *Terra: through December 2014, will continue until Ed4 ADMs completed*
- Edition 4 processing
  - *Aqua: through December 2010, continuing*
  - *Terra: through April 2011, continuing*

CERES VIIRS

- VIIRS on SNPP (1330 LT ECT), 0.75 km pixel resolution
- Ed1 delivered, processing begun
  - *Jan – July 2012, continuing*

Some Properties in CERES-MODIS Edition4 and CERES-VIIRS Edition 1

Single Scanner Footprint (SSF) TOA/Surface Fluxes and **Clouds**

Radiation Parameters
0.65, 1.2, & 1.6 2.1 µm Reflectances
3.7, 6.7, 10.8 µm Temperatures
12 or 13.3 µm Temperatures
Broadband Albedo
Broadband OLR
Clear-sky Skin Temperature
Clear-sky albedo & OLR
FOV Lat, Lon
FOV SZA, VZA, RAZ

Single-layer Cloud Properties

- **Cloud Fraction, Phase**
- **Visible Optical Depth**
  - **0.65 µm non-snow, 1.24-µm snow/ice**
- **IR emissivity**
- **Droplet/Xtal effective radius (Re)**
  - **3.7, 1.24*, 2.1 (MODIS), 1.6 (VIIRS)**
- Liquid/Ice Water Path
- **Effective Temp**, Height, Pressure
- Top & Bottom: Pressure, Temperature, Height

- Cloud properties in **bold** retrieved directly, others from those parameters
- Re in green are secondary retrievals, *MODIS 1.24 Re not valid

SSF Multilayer Cloud Properties (Ice Over Water)

- Channels used retrieve upper & lower layer clouds
  - MODIS: 10.8 & 13.3 µm
  - VIIRS: 10.7 & 12.0 µm

Parameters

- **Multilayer fraction (ice over water)**
- **Lower cloud**
  - top temperature, height pressure
  - optical depth
  - liquid Re: 3.8, 1.24, and 1.6 (VIIRS) or 2.1 (MODIS) µm
- **Upper cloud**
  - top temperature, height pressure
  - optical depth
  - ice Re: 3.8, 1.24, and 1.6 (VIIRS) or 2.1 (MODIS) µm

References for CERES Edition 4

Basis for Edition 4: updated versions of

Minnis, P., S. Sun-Mack et al., 2011: CERES Edition-2 Cloud Property retrievals using TRMM VIRS and Terra and Aqua MODIS data. Part I: Algorithms. Part II: Examples of average results and comparison with other data. *IEEE Trans. Geosci. Remote Sens.*, **49**, 4374-4430.

Ed 4 additions

Yang, P., G. W. Kattawar, G. Hong, P. Minnis, and Y. X. Hu, 2008: Uncertainties associated with the surface texture of ice particles in satellite-based retrieval of cirrus clouds: Part II. Effect of particle surface roughness on retrieved cloud optical thickness and effective particle size. *IEEE Trans. Geosci. Remote Sens.*, **46**, 1948-1957.

Minnis, P., S. Sun-Mack, et al., 2010: CERES Edition 3 cloud retrievals. *AMS 13th Conf. Atmos. Rad.*, Portland, OR, June 27 – July 2, 5.4.

Sun-Mack, S., P. Minnis, Y. Chen, S. Kato, Y. Yi, S. Gibson, P. W. Heck, and D. Winker, 2014: Regional apparent boundary layer lapse rates determined from CALIPSO and MODIS data for cloud height determination. *J. Appl. Meteorol. Climatol.,* **53**, 990-1011.

Multilayer Algorithm

Chang, F.-L., P. Minnis, B. Lin, M. Khaiyer, R. Palikonda, and D. Spangenberg, 2010: A modified method for inferring cloud top height using GOES-12 imager 10.7- and 13.3-μm data. *J. Geophys. Res.*, **115**, D06208, doi:10.1029/2009JD012304.

VIIRS Edition-1

- Differences from Aqua Ed4

  - no WV or CO2 channels

  - affects polar mask, ice cloud height & ML detection/retrieval

  - 11-12 µm BTD used in place of CO2 channel

  - not a bad replacement

- Thick ice cloud-top height correction applied

  - no need for external post facto correction

  - affects cloud base and is inconsistent with VIIRS Ed1

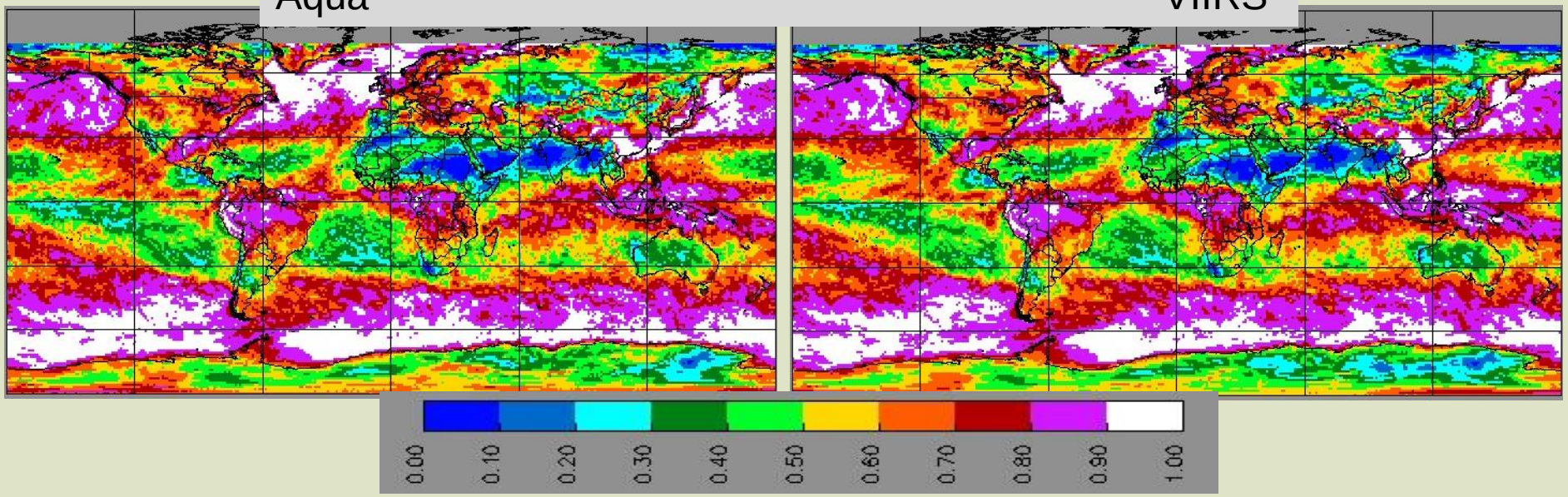
- Uses revised water droplet model

  - 3.7-µm channel has better wavelength & solcon weighting

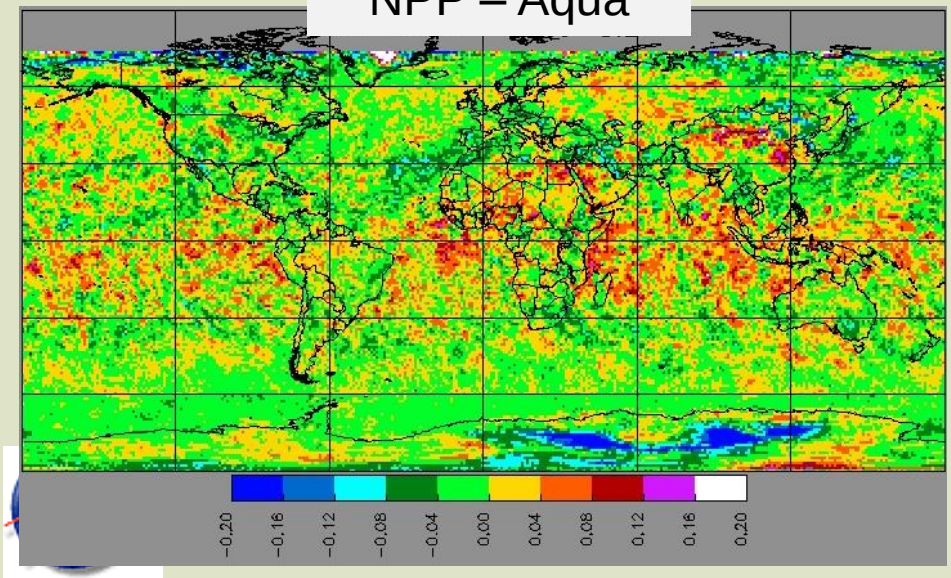
Total Cloud Amounts, Day, February 2012

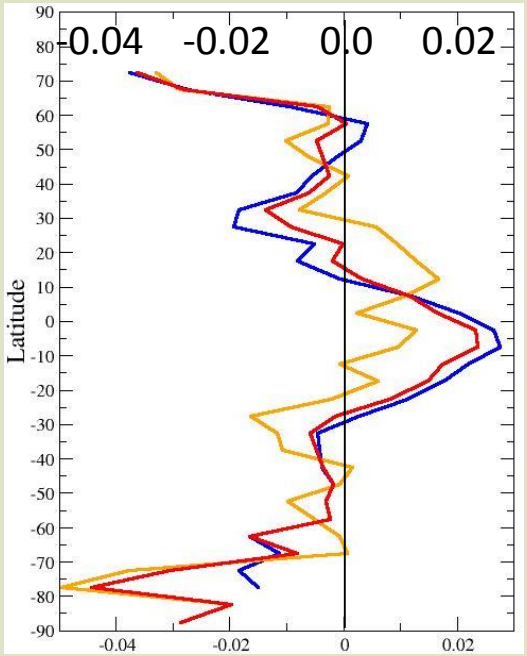
Aqua

VIIRS



NPP – Aqua

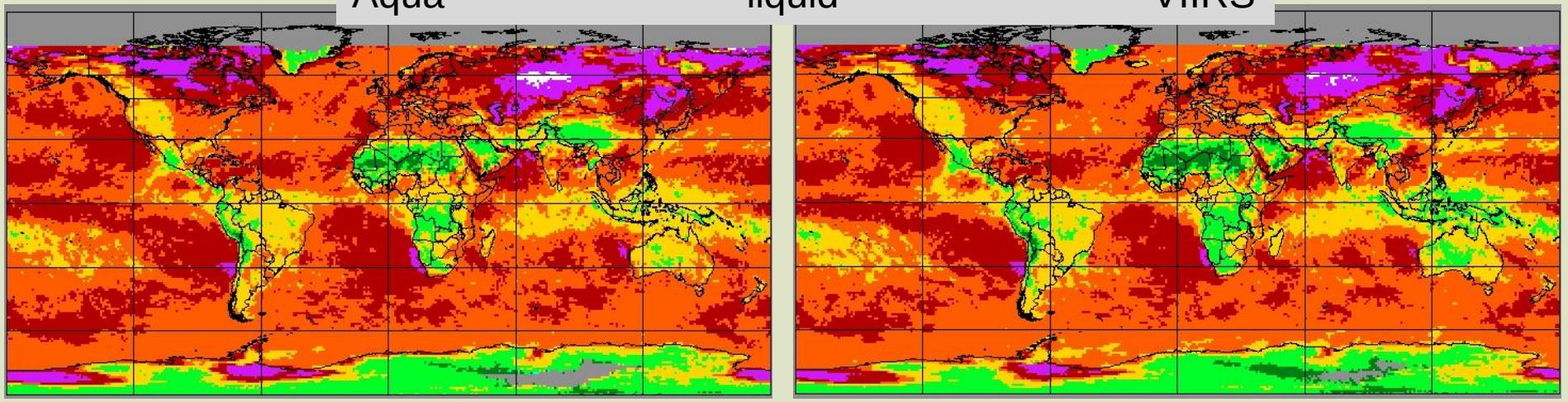




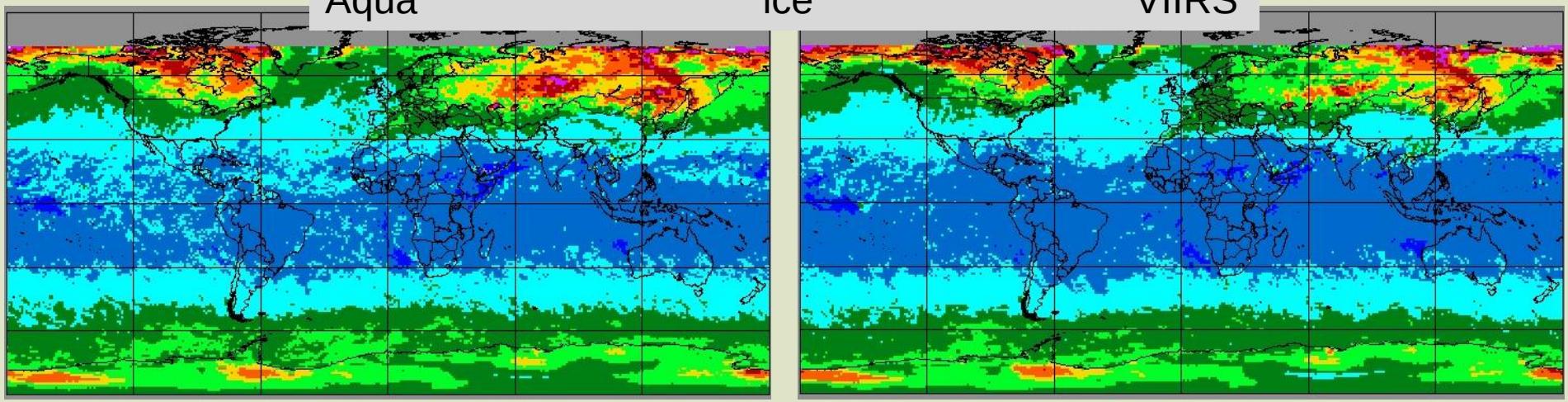
CLOUDS AND THE EARTH'S RADIANT ENERGY SYSTEM
CERES

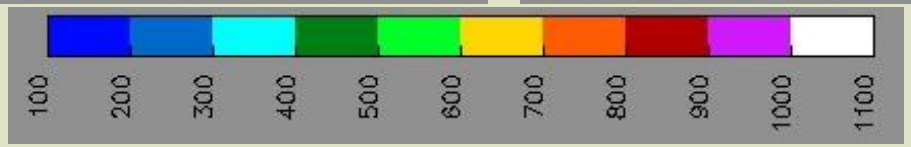
Cloud Effective Pressure (hPa), Day, February 2012

Aqua liquid VIIRS



Aqua ice VIIRS



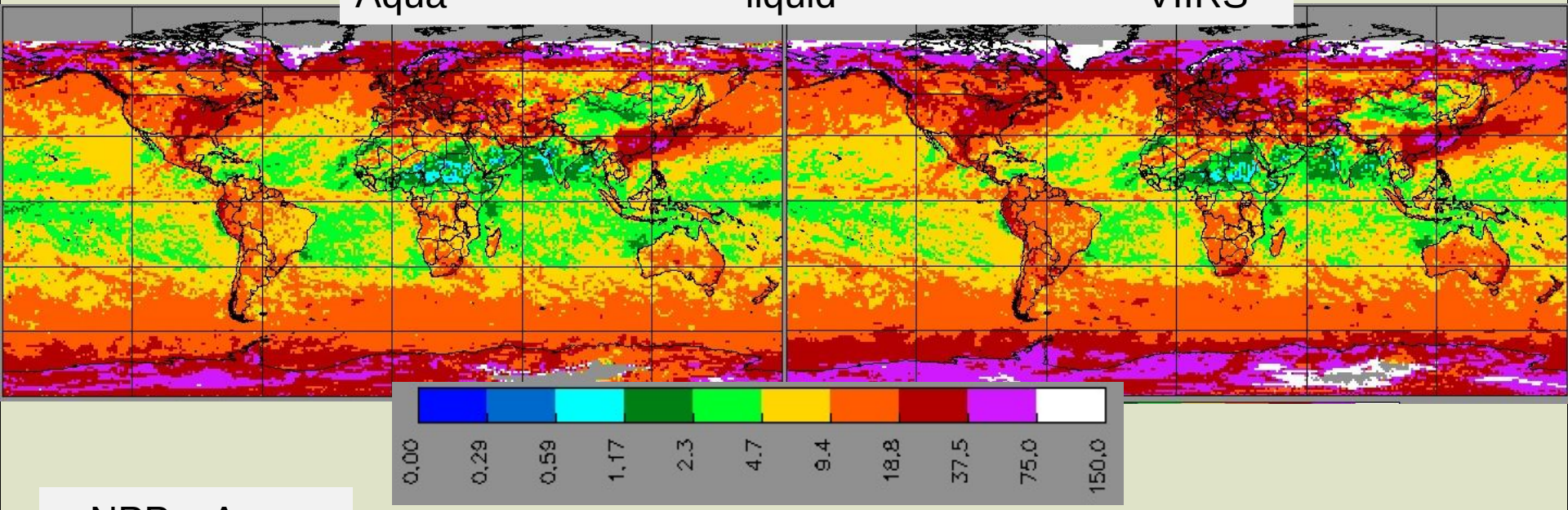


Mean Cloud Parameter Differences, February 2012
VIIRS - MODIS

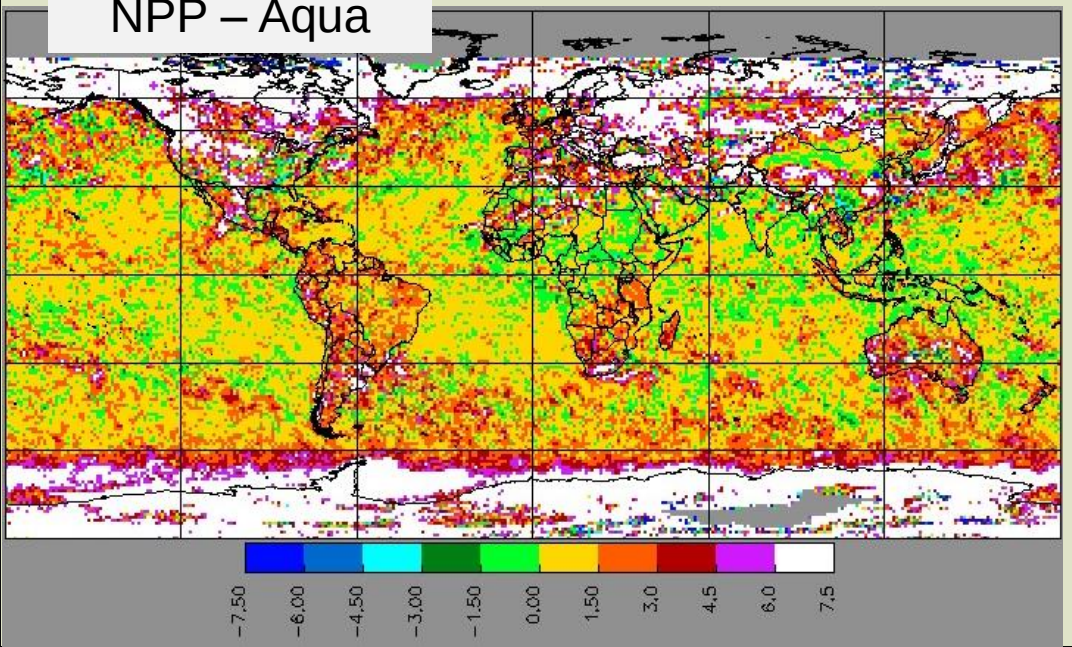
		Day			Night		
Parameter		Global	NonPolar	Polar	Global	NonPolar	Polar
CF	Water	0.004	0.000	0.031	-0.011	-0.010	-0.017
	Ice	-0.009	-0.001	-0.068	0.001	-0.002	0.017
	Total	0.001	0.003	-0.021	-0.008	-0.011	0.007
Zeff (km),	Water	0.17	0.18	0.14	0.09	0.08	0.14
	Ice	0.36	0.37	0.26	0.17	0.12	0.44
	Total	0.27	0.31	-0.01	0.13	0.08	0.43
Peff (mb),	Water	-13.4	-13.4	-13.1	-7.8	-6.8	-14.4
	Ice	-18.6	-18.7	-17.4	-11.0	-8.1	-30.3
	Total	-15.5	-17.7	1.6	-10.6	-7.2	-32.3
Teff (K),	Water	-1.1	-1.1	-0.9	-0.5	-0.5	-0.7
	Ice	-2.4	-2.5	-1.5	-0.8	-0.5	-2.6
	Total	-1.8	-2.0	-0.2	-0.7	-0.4	-2.5

Mean Cloud Optical Depths, February 2012

Aqua liquid VIIRS



NPP – Aqua



- Patterns very similar
- VIIRS > Aqua in most locations
  - *likely higher resolution*
- Largest differences over snow and land (1.24 µm)
  - *different models*

Mean Cloud Parameter Differences, February 2012
VIIRS - MODIS

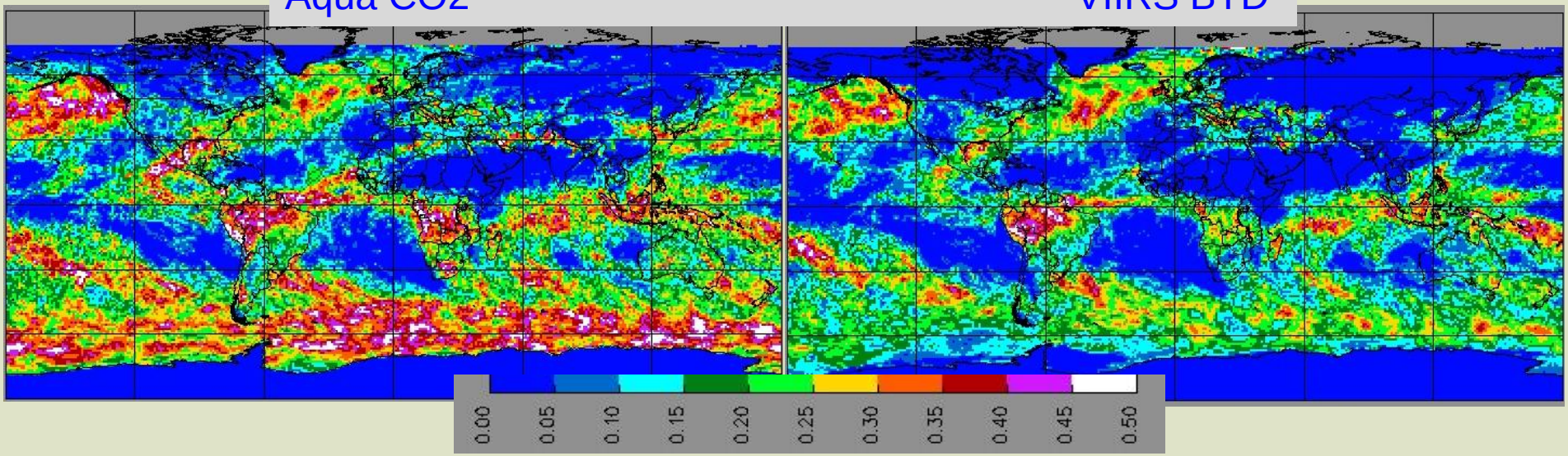
Parameter		Day			Night		
		Global	Non Polar	Polar	Global	Non Polar	Polar
Tau	Water	2.61	1.56	10.55	-0.14	-0.18	0.15
	Ice	-0.59	-0.19	-3.62	-0.08	-0.03	-0.39
	Total	1.44	0.83	6.07	-0.19	-0.10	-0.79
Re (μm)	Water	-0.7	-0.9	0.3	-0.2	-0.3	0.3
	Ice	0.0	0.4	-2.4	-2.3	-2.6	-0.6
	Total	-1.0	-0.7	-3.6	-1.2	-1.4	0.1
LWP (gm^{-2})		37.6	15.1	207.0	3.3	-0.7	28.9
IWP (gm^{-2})		9.4	21.8	-84.3	7.1	8.0	1.2
TWP (gm^{-2})		21.3	14.1	76.1	2.6	3.2	-1.1

- VIIRS water cloud tau > Aqua everywhere, Re < Aqua Re
  - *LWP > Aqua LWP*
- VIIRS nonpolar ice cloud tau < Aqua, Re slightly > Aqua
  - *IWP slightly > Aqua IWP*

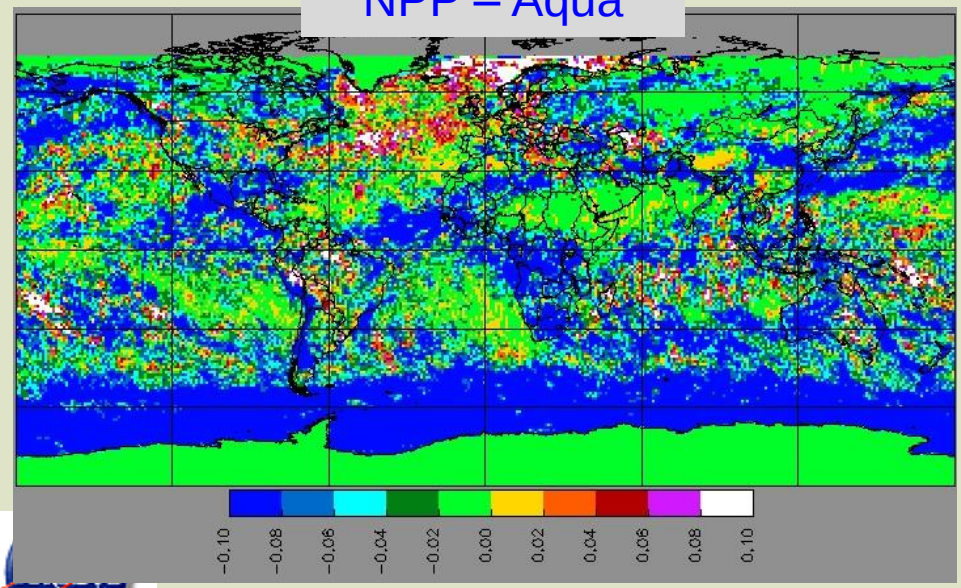
Multi-Layer Cloud Amounts, Day, February 2012

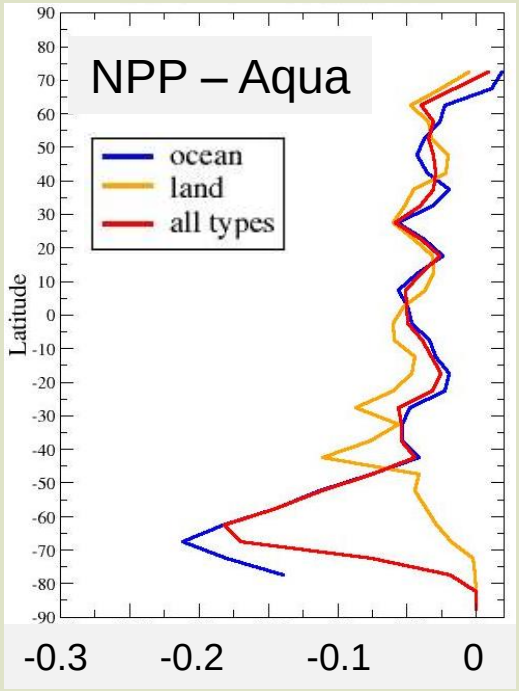
Aqua CO2

VIIRS BTD



NPP – Aqua



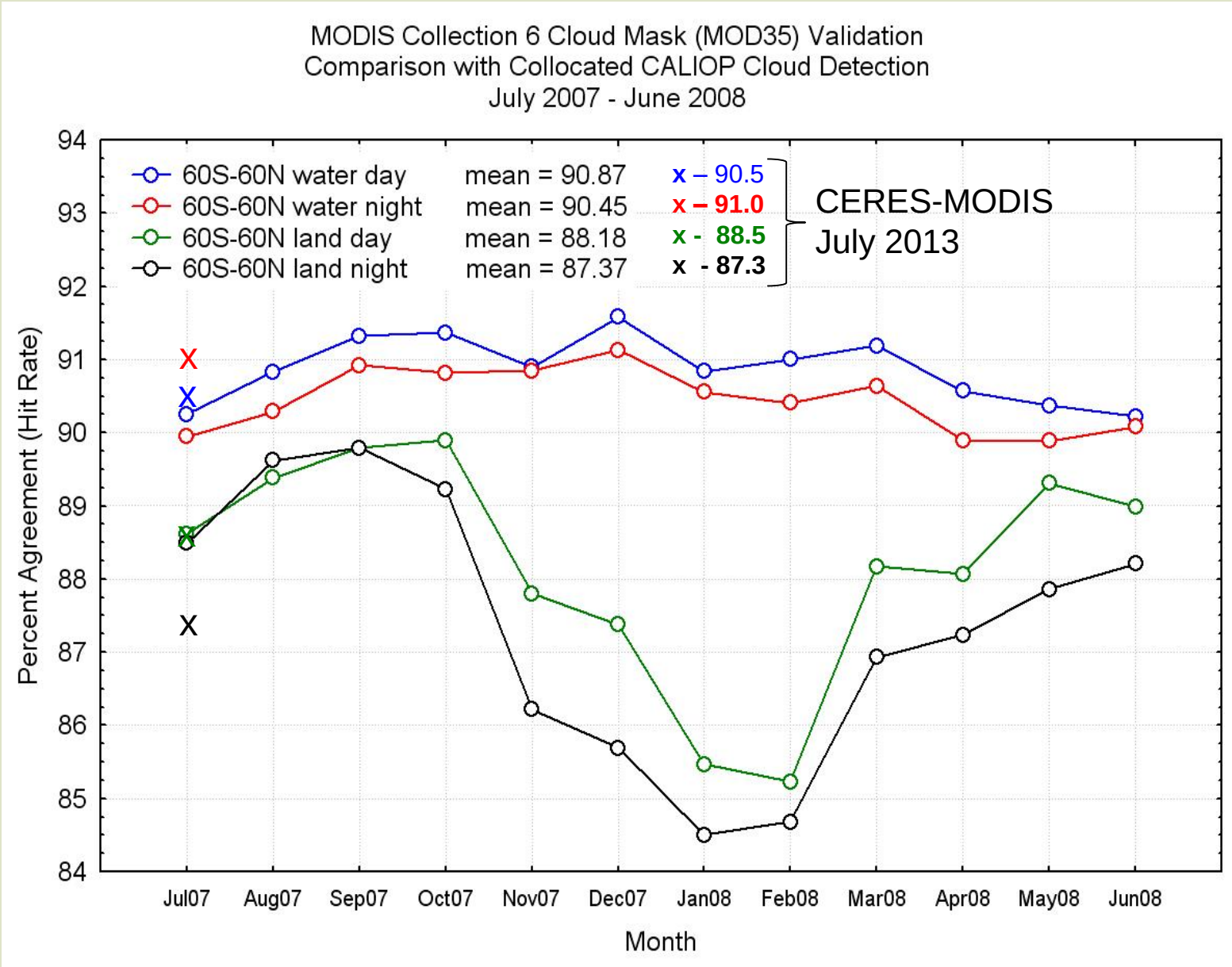


Cloud Fraction Comparison, Aqua Ed4 vs CALIPSO, July 2013

DAYTIME	FRACTION CORRECT	FALSE-ALARM RATE	HEIDKE SKILL SCORE	NUMBER OF MATCHES
Nonpolar, Land, Snow/Ice-free	0.885	0.046	0.76	301696
Polar, Land, Snow/Ice-free	0.887	0.036	0.73	96599
Nonpolar, Ocean, Snow/Ice-free	0.905	0.062	0.76	768435
Polar, Ocean, Snow/Ice-free	0.925	0.061	0.68	104176
Global, Land & Ocean, Snow/Ice-covered	0.887	0.062	0.67	248068
NIGHTTIME				
Nonpolar, Land, Snow/Ice-free	0.873	0.043	0.74	299214
Polar, Land, Snow/Ice-free	0.884	0.060	0.73	64369
Nonpolar, Ocean, Snow/Ice-free	0.910	0.042	0.72	846030
Polar, Ocean, Snow/Ice-free	0.943	0.030	0.63	55305
Global, Land & Ocean, Snow/Ice-covered	0.765	0.104	0.49	534541

- VIIRS Ed 1 values slightly lower
  - angle and temporal matching differences

CERES & MAST Collection 6 Detection Accuracy wrt CALIOP



- CERES fraction correct nearly identical to that of MODIS Collection 6

Cloud Phase, Aqua MODIS vs CALIPSO, July 2013

DAYTIME	FRACTION CORRECT	Ice FAR	Water FAR	HEIDKE SKILL SCORE	NUMBER OF MATCHES
Nonpolar, Land, Snow/Ice-free	0.952	0.010	0.096	0.902	56830
Polar, Land, Snow/Ice-free	0.939	0.028	0.088	0.878	14655
Nonpolar, Ocean, Snow/Ice-free	0.973	0.023	0.030	0.942	282342
Polar, Ocean, Snow/Ice-free	0.948	0.052	0.052	0.826	29643
Global, Land & Ocean, Snow/Ice-covered	0.914	0.114	0.079	0.763	42475
NIGHTTIME					
Nonpolar, Land, Snow/Ice-free	0.904	0.043	0.216	0.766	55216
Polar, Land, Snow/Ice-free	0.862	0.116	0.165	0.720	11695
Nonpolar, Ocean, Snow/Ice-free	0.950	0.076	0.034	0.894	287706
Polar, Ocean, Snow/Ice-free	0.882	0.201	0.040	0.763	17502
Global, Land & Ocean, Snow/Ice-covered	0.876	0.130	0.064	0.539	127057

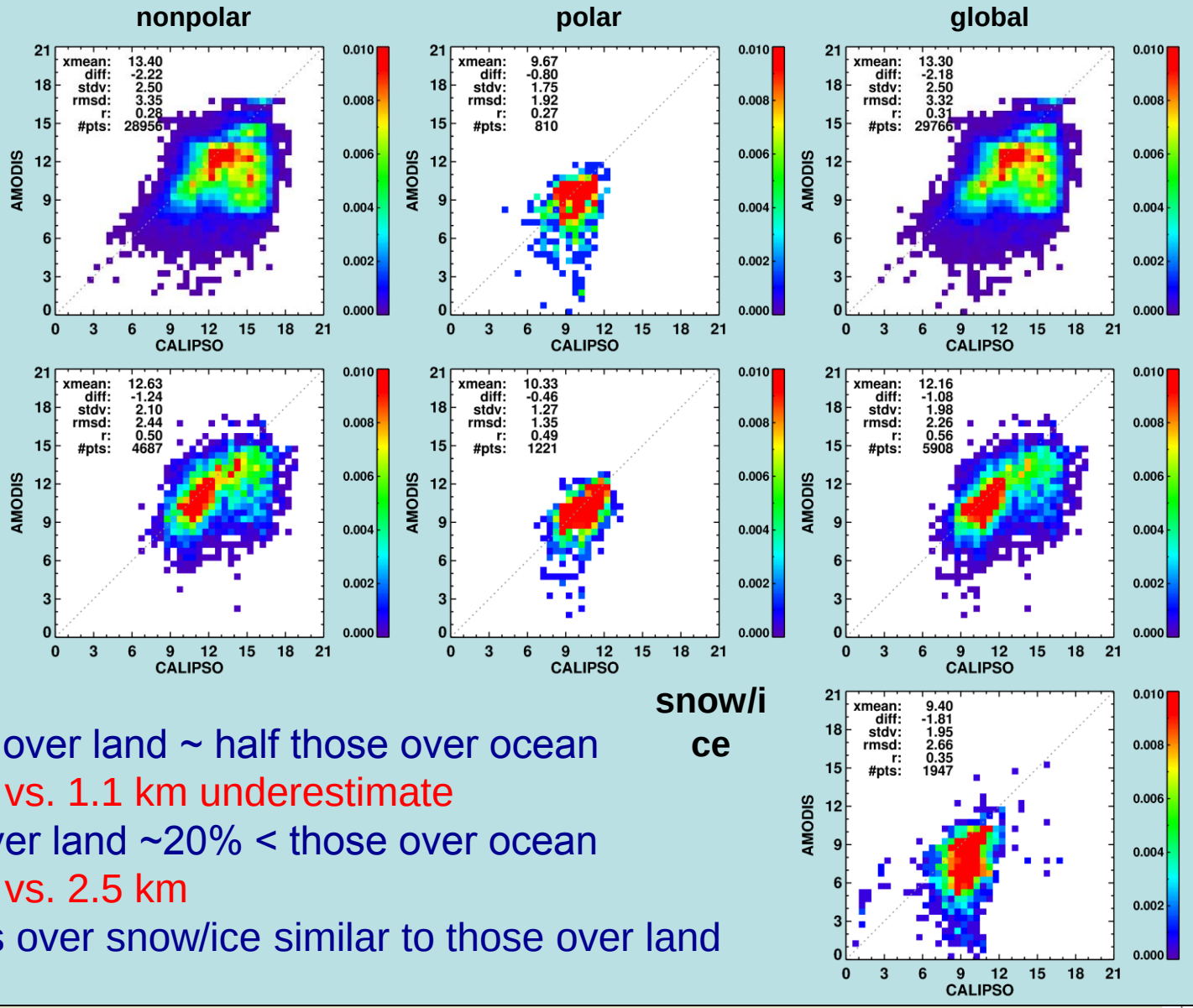
Cloud Height Difference (Aqua Ed4 – CALIPSO), July 2013, single-layer liquid

Non-opaque **DAYTIME**	MEAN DIFF [km] (AVHRR-CALIPSO)	RMSD [km]	R	NUMBER OF MATCHES
Global, Ocean, Snow/Ice-free	0.02	0.73	0.64	64412
Global, Land, Snow/Ice-free	-0.32	1.15	0.65	8749
Global, Land & Ocean, Snow/Ice-covered	-0.06	0.85	0.69	9432
NIGHTTIME				
Global, Ocean, Snow/Ice-free	0.18	0.81	0.63	57039
Global, Land, Snow/Ice-free	0.03	0.91	0.75	5138
Global, Land & Ocean, Snow/Ice-covered	0.36	0.93	0.43	3687
opaque **DAYTIME**				
Global, Ocean, Snow/Ice-free	-0.11	0.69	0.83	129972
Global, Land, Snow/Ice-free	-0.15	0.85	0.89	21064
Global, Land & Ocean, Snow/Ice-covered	-0.53	1.09	0.83	21048
NIGHTTIME				
Global, Ocean, Snow/Ice-free	0.03	0.65	0.76	122158
Global, Land, Snow/Ice-free	-0.08	0.82	0.87	12449
Global, Land & Ocean, Snow/Ice-covered	0.28	0.95	0.59	8151

- Largest biases over ice/snow, smallest over ocean
- STD of differences generally < 1.0 km, over ocean < 0.8 km

Cloud Top Altitude, Aqua MODIS vs CALIPSO, July 2013

ice phase, daytime, non-opaque



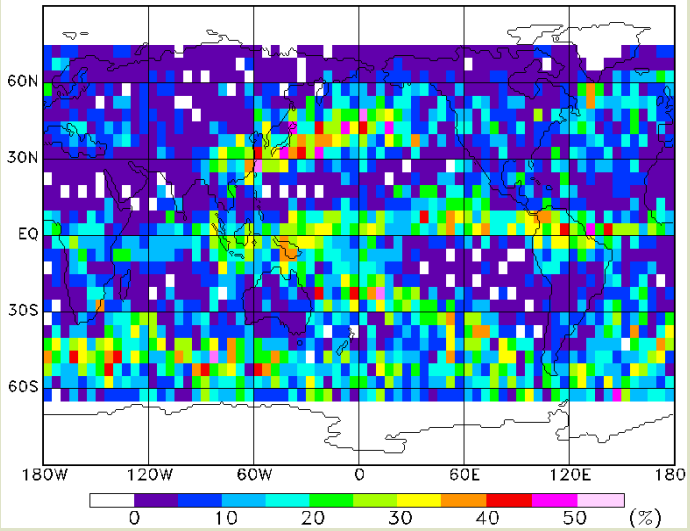
- Biases over land ~ half those over ocean
  - 2.2 vs. 1.1 km underestimate
- STD over land ~20% < those over ocean
  - 2.0 vs. 2.5 km
- Results over snow/ice similar to those over land

Cloud Height Difference (Aqua Ed4 – CALIPSO), July 2013, single-layer **ice** **Non-opaque**

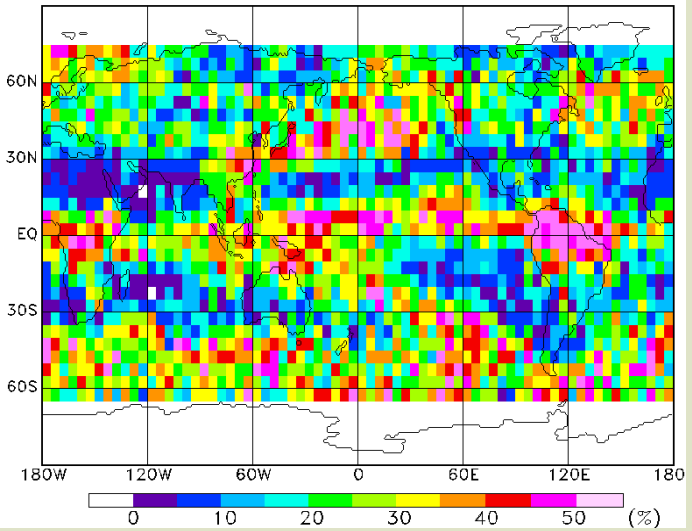
DAYTIME	MEAN DIFF [km]	RMSD [km]	R	NUMBER OF MATCHES
Global, Ocean, Snow/Ice-free	-2.18	3.32	0.31	29766
Global, Land, Snow/Ice-free	-1.08	2.26	0.56	5908
Global, Land & Ocean, Snow/Ice-covered	-1.81	2.66	0.35	1947
NIGHTTIME				
Global, Ocean, Snow/Ice-free	-0.45	1.81	0.71	27596
Global, Land, Snow/Ice-free	0.01	1.95	0.69	14053
Global, Land & Ocean, Snow/Ice-covered	-2.18	4.00	0.27	56329

Comparison of CERES Multilayer Cloud Amount with CALIPSO+CloudSat

CERES Multi



CALIPSO+CloudSat



- Collocated data: 2010 April daytime
- 5° -box average:

	CERES Multi	CL+CS Multi
Global	10.2%	23.4%
Ocean	12.1%	24.3%
Land	7.0%	21.7%

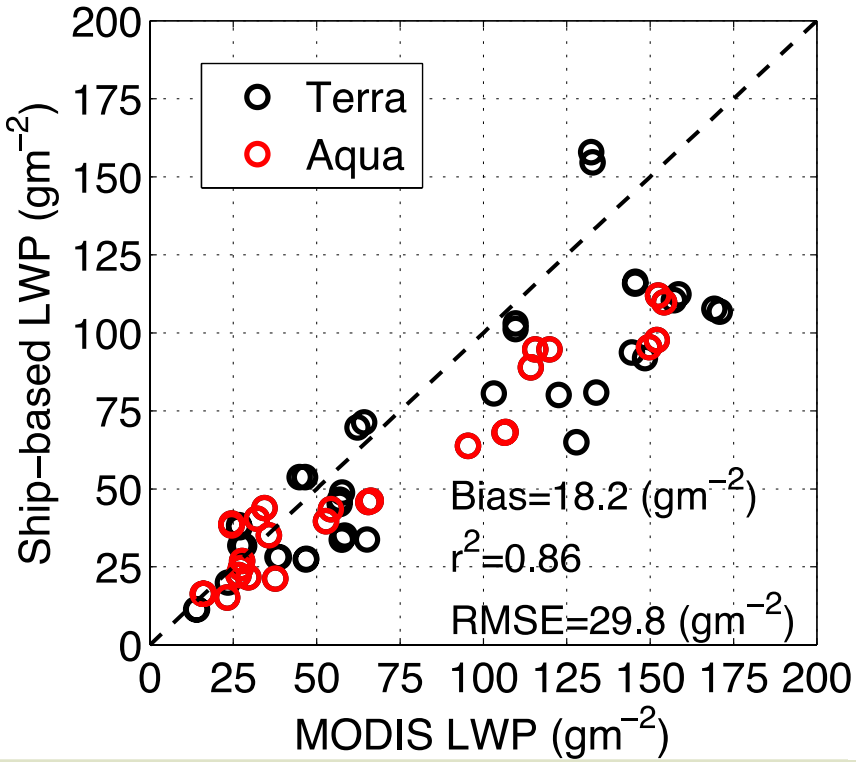
Cloud Height Difference (Aqua Ed4 – CALIPSO), July 2013, single-layer **ice**
Opaque, Correction applied externally

DAYTIME	MEAN DIFF [km]	RMSD [km]	R	NUMBER OF MATCHES
Global, Ocean, Snow/Ice-free	-0.98	1.91	0.78	78408
Global, Land, Snow/Ice-free	-0.54	1.70	0.76	32138
Global, Land & Ocean, Snow/Ice-covered	-0.38	1.61	0.37	6379
NIGHTTIME				
Global, Ocean, Snow/Ice-free	-0.80	1.79	0.84	81889
Global, Land, Snow/Ice-free	-0.69	1.94	0.76	28307
Global, Land & Ocean, Snow/Ice-covered	-1.67	2.68	0.55	43158

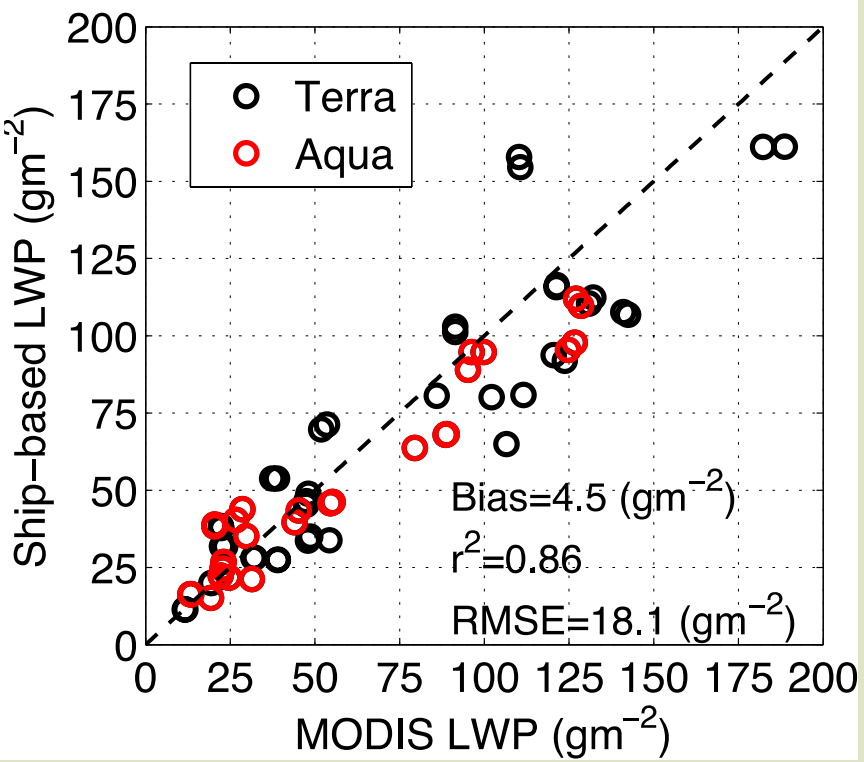
Marine Stratus LWP Comparison, **MAGIC** vs **CERES** MODIS

ASR MAGIC deployment instrumented a Hawaii-LA freighter with ARM instruments for 1 year. MWR was included. June-July 2013 MODIS data matched with ship. LWP computed from COD & Re two ways.

Homogeneous: LWP = 0.667 τ * Re



Adiabatic: LWP = 0.555 τ * Re



- Adiabatic bias only 1/4th that of homogeneous assumption
  - recommend use adiabatic approach for LWP computations
    - *at least, for stratus*

Summary

- CERES MODIS Ed4 marks a significant improvement over Ed2

- CERES VIIRS Ed1 shows consistency with CERES MODIS Ed4
  - small differences due to channel, resolution, and different models

- Most parameters have well characterized uncertainties relative to CALIPSO

- > 1 decade of data available for variability studies

- Results are available at SSF and imager pixel resolution

- Merged CERES, CloudSat, CALIPSO, and MODIS data (C3M) has been developed for further research
  - available for download

Data ordering websites for SSF and CCCM

SSF: CERES Ordering and Visualization Tool
http://ceres.larc.nasa.gov/order_data.php
From here, you get the choice of Edition3 or Edition4 for SSF.

SSF: Langley ASDC SSF main page
https://eosweb.larc.nasa.gov/project/ceres/ssf_table
Edition 3 is here, and Edition4 is under Next Edition Data.

CCCM main page
https://eosweb.larc.nasa.gov/project/ceres/cccm_table